SPECIFICATION

SINKER ELECTRIC DISCHARGE MACHINING METHOD AND APPARATUS

Field of the Invention

The present invention relates to a sinker electric discharge machining method for forming a required cavity in the workpiece by causing electric discharge in a microscopic gap formed between a tool electrode and the conductive workpiece.

Background of the Invention

Before carrying out electric discharge machining, a tool electrode is manufactured, having a shape that is the complement of a cavity to be formed, and having a size that is slightly reduced compared to the cavity. The tool electrode is positioned close enough to a workpiece to induce electric discharge. A microscopic gap is filled with dielectric fluid.

If a power pulse is applied to the gap, after a delay time electric discharge occurs and electrical current begins to flow via the gap. The delay time depends on the state of the gap and can not be predicted. If the application of the power pulse to the gap is stopped, insulation is restored into the gap. Thus, electric discharge is intermittently generated in the gap, and material is removed a little at a time from the workpiece. Pieces of the removed material are called chips, and are washed away from the gap by dielectric fluid. The gap is restricted to a size that enables electric discharge to be efficiently induced. The size of the gap is a few μm to a few tens of μm. The tool electrode is moved a little at a time in a Z axis direction towards the workpiece, in response to removal of the workpiece material.

A conventional sinker electric discharge machining apparatus includes a computerized numerical controller and an automatic programming device. The computerized numerical controller controls movement of the tool electrode and supply of power pulses etc. in accordance with an NC program. Data representing the size and surface roughness of a cavity to be formed,

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material properties of the tool electrode and workpiece, etc. is input to the automatic programming device. Based on such data, the automatic programming device automatically creates an NC program for forming the cavity in the minimum machining time. A process for forming the cavity is divided into a plurality of steps in which power pulse conditions and feed amount are set. The feed amount is a distance that the tool electrode is advanced in the Z axis direction towards the workpiece. If the tool electrode is moved by the set feed amount, the process proceeds to the next step in accordance with the NC program. At this time, setting of the power pulse conditions is switched. The power pulse conditions include, for example, on-time, off-time, current peak and voltage. In a first step, the feed amount is a distance from a reference position. Normally, the reference position is a position separated from an upper surface of the workpiece in the Z direction by the extent of a gap that will enable electric discharge to be induced. In the first step, a large power pulse is supplied to the gap, and the cavity is rough machined in the workpiece. If the large power pulse is supplied to the gap, the time required for machining is shortened, but the machined surface is undesirably rough. The feed amount in a second step is a distance from the tool electrode position at the time that the first step is completed. The feed amount in a third step is a distance from the tool electrode position at the time that the second step is completed. As the process advances to the second step and the third step of the process, the power pulse applied to the gap becomes smaller. In a final finishing step, extremely small power pulses are adopted for the purpose of making the surface roughness of the cavity fine. In the finishing step, ideally, the cavity is formed to the required dimensions.

In actual fact, however, the undesirable removal of excess material from the workpiece constitutes a fatal mistake, which means that the cavity is formed a few μm to over ten μm smaller than the required dimensions. The dimensions of the cavity are measured after formation

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of the cavity. Before measurement, the workpiece is washed and chips that are stuck to the workpiece are completely removed. In this way, an error between the measured dimensions and the required dimensions is obtained. The fact that surplus material having a dimension of a few μm to over ten μm remains may not be a major problem. However, in recent years, dimensional precision of a few μm or less has become necessary. In manufacture of certain products, dimensional precision of 1 μm has become necessary. A second process for removing surplus material without impairing the low surface roughness is called "additional machining".

Fig. 5 shows a tool electrode **17** and a workpiece **18** before additional machining. **Z** represents the dimension of material to be removed, of a few μm to over ten μm. **A** represents the position of the tool electrode at the time when the finishing step is completed. A feed amount **dZ** equal to value **Z** is set in an NC program. In the additional machining a problem often arises where the NC program terminates without electric discharge being induced, even if the tool electrode **17** is moved from position **A** to position **B**. A gap size that at which electric discharge can be induced is mainly dependent on the magnitude of the power pulse. However, even under the same power pulse conditions, the gap size at which electric discharge can be induced differs due to the amount of chips. Value **H** represents the gap size at the time where the finishing step is completed. Value **G** represents the gap size at the time where the additional machining starts. Electric discharge generated between the tool electrode and the workpiece is called primary discharge. Electric discharge arising through the microscopic chips is called secondary discharge. During machining, the chips float in the gap or attach to the workpiece. It is well known that if a greater amount of chips increases the occurrence of secondary discharge, the gap size is increased. At the time where additional machining starts, there are hardly any chips because of the washing at the time of measurement. Therefore, if an error e between the

value **H** and the value **G** is larger than the value **Z**, electric discharge machining cannot be accomplished at all.

Japanese patent publication 2001-9639 discloses causing conductive powder to be attached to the surface of the workpiece, in order to prevent variation in the gap size.

Japanese patent publication 60-3933 discloses an electric discharge machine provided with a timer circuit capable of setting machining time. In finishing step for removing very fine material, it is possible to terminate machining when the machining has reached a set time, instead of using feed amount.

The object of the present invention is to provide a sinker electric discharge machining method and device for accurately removing material having a very small size of a few μm to over ten μm using electric discharge.

Disclosure of the Invention

In order to achieve the above described object, the electric discharge machining method of one aspect of the present invention comprises the steps of: setting machining conditions, obtaining a removal volume (**V**), obtaining a removal volume rate (**Vm**) corresponding to the set machining conditions, setting machining time (**T**) based on the removal volume (**V**) and the removal volume rate (**Vm**), electric discharge machining a workpiece under the set machining conditions, and completing electric discharge machining when the set machining time (**T**) has elapsed from the start of electric discharge machining.

According to another aspect of the present invention, the electric discharge machining method comprises the steps of: setting machining conditions, obtaining a removal volume (**V**), obtaining a removal volume per single discharge (**Vp**) corresponding to the set machining conditions, setting a number of electric discharges (**P**) based on the removal volume (**V**) and the removal volume per single discharge (**Vp**), electric discharge machining a workpiece under the

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set machining conditions, and completing electric discharge machining when the set number of discharges (P) have been completed from the start of electric discharge machining.

Preferably, the removal volume (V) is obtained based on a dimension of the material to be removed (d) and a removal surface area (S).

According to yet another aspect of the present invention, a sinker electric discharge machining apparatus for machining a workpiece using a tool electrode comprises:

a device (1) for supplying a current pulse having a current peak of 0.2A - 2A and an on-time of 0.5 μseconds to 5 μseconds to a gap formed between the tool electrode and the workpiece;

a storage device (40) for storing a database correlating removal volume rate (Vm) with machining conditions, and storing removal volume (V);

an input device (20) for setting machining conditions;

a calculating device for extracting the removal volume rate (Vm) corresponding to the set machining conditions from the storage device, and calculating a machining time (T) based on the removal volume (V) and the removal volume rate (Vm); and

a device for completing electric discharge machining when the machining time (T) has elapsed from the start of electric discharge machining.

According to a still further aspect of the present invention, a sinker electric discharge machining apparatus for machining a workpiece using a tool electrode comprises:

a device (1) for supplying a power pulse having a current peak of 0.2A - 2A and an on-time of 0.5 μseconds to 5 μseconds to a gap formed between the tool electrode and the workpiece;

a storage device (**40**) for storing a database correlating removal volume per single discharge (**Vp**) with machining conditions, and storing removal volume (**V**);

an input device (**20**) for setting machining conditions;

a calculating device for extracting the removal volume per single discharge (**Vp**) corresponding to the set machining conditions from the storage device, and calculating a number of electric discharges (**P**) based on the removal volume (**V**) and the removal volume per single discharge (**Vp**); and

a device for completing electric discharge machining when the number of electric discharges (**P**) have been completed from the start of electric discharge machining.

According to the present invention, even when variation in gap size arising under the same power pulse conditions is larger than a feed amount, it is possible to remove material of microscopic dimensions.

Brief Description of the Drawings

Fig. 1 is a block diagram of a sinker electric discharge machining apparatus of the present invention.

Fig. 2 is a block diagram of a gate signal generator of Fig. 1.

Fig. 3 is a flowchart showing a sinker electric discharge machining method of the present invention.

Fig. 4 is a flowchart showing a sinker electric discharge machining method of the present invention.

Fig. 5 is a cross sectional drawing of a tool electrode and a workpiece before additional machining.

Best Mode for Embodying the Invention

A sinker electric discharge machining apparatus and machining method will now be described in detail with reference to Fig. 1, Fig. 2, Fig. 3, Fig. 4 and Fig. 5.

As shown in Fig. 1, the electric discharge machining apparatus includes a power supply **1** and a controller **2**, in addition to a sinker electric discharge machine. The sinker electric discharge machine includes a head **3** to which a tool electrode **17** is attached, and a table **4** on which the workpiece **18** is fixed. The head **3** is provided on a column (not shown), and is movable in the Z axis direction by a linear servo motor **91** . The table **4** is mounted on a saddle **5** and is movable in the X axis direction by a linear servo motor **92**, while the saddle **5** is mounted on a bed and is movable in the Y axis direction by a linear servo motor **93**. The Z axis is the vertical axis, and orthogonal XY axes are horizontal axes.

The power supply **1** is one example of means that can repeatedly supply a current pulse having a current peak of 0.2A - 2A and an on-time of 0.5 μsecond - 5 μseconds to a gap. The power supply **1** includes a switching circuit and a d.c. power supply **16** connected in series with the switching circuit. The switching circuit is made up of series circuits **11, 12, 13, 14, 15-1 - 15-N** having switching elements **SW**, current limiting resistance elements **R**, and backflow prevention diodes **D** connected in series. The plurality of series circuits **11, 12, 13, 14, 15-1 - 15-N** are all connected in parallel with each other. One terminal of the d.c. power supply **16** is connected to the tool electrode **17**, while the other terminal is connected to the workpiece **18**. The output voltage of the d.c. power supply **16** can be set to 90V, 120V, 150V and 200V. The power supply **1** and the sinker electric discharge machine are connected using a low inductance cable **19**, such as a shielded cable or coaxial cable. The on-time and current peak of a current pulse flowing in the gap is determined by on/off operation of the plurality of switching elements **SW**. A switching element **SW** is a field effect transistor capable of high speed on/off operation

of less than 1 μsecond, and preferable 500 nanoseconds. This makes it possible to supply current pulse having an on-time of 0.5 μseconds - 5 μseconds to the gap, and makes it possible to increase the frequency of repeating electric discharge.

The series circuits **15-1 - 15-N** respectively include current limiting resistance elements **R** of **30Ω**, and are used from the rough step to the finishing step. For example, if only four series circuits **15-1 - 15-4** are connected to a 90V d.c. power supply **16**, it is possible to supply a current pulse having a current peak of 12A to the gap.

The series circuits **11 - 14** are circuits for supplying a current pulse having a current peak of 2A or less to the gap. The series circuits **11 - 14** respectively include current limiting resistance elements **R** of 450Ω, 240 Ω, 120 Ω and 60 Ω. A current pulse having a current peak of 0.2A is supplied from the 90V d. c. power supply **16** to the gap by means of the series circuit **11**. Current pulses having current peaks of about 0.37A, 0.75A, and 1.5A are supplied to the gap from the d.c. power supply by means of the series circuits **12, 13** and **14**, respectively. The series circuit **11 - 14** can control the energy of a single current pulse flowing through the gap to be constant, and so are suitable for additional machining. For example, using a copper tool electrode, additional machining is carried out on a steel workpiece having a surface area of 5 x 10 mm^2. In this case, material is removed at a rate of 0.08 μm/minute - 0.1 μm/minute by supplying a current pulse having an on-time of 1 μsecond and a current peak of 0.4A to the gap.

An additional d.c. power supply of 200V or higher (not shown) having a resistance element of 150Ω or greater connected is preferably connected in parallel with the d.c. power supply **16**. The use of this additional d.c. power supply enlarges the gap, and has the effect of stabilizing the additional machining. In addition, a delay time from application of a voltage to the gap until electric discharge is generated is made as small as possible.

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The controller **2** includes a calculating device **10**, an input device **20**, a display device **30**, a storage device **40**, a gate signal generator **50**, a position recognition device **80**, and a motor controller **90**. The calculating device **10** is basically a main control circuit made up of at least one CPU, a cache memory, a ROM, a CPU controller and some interfaces. Preferably, the calculating device **10** contains a computer aided design system, and has three-dimensional shape data for the cavity or the tool electrode **17**. The input device **20** contains a keyboard, a switch, a mouse and a drive device as storage medium. The display device **30** is a CRT or an LCD. The storage device **40** has a memory module (SDRAM) and a hard disc drive. The motor controller **90** controls the linear servo motors **91, 92, 93** in accordance with movement command data from the calculating device **10**. A position detection signal is sent from a linear scale (not shown) attached to the sinker electric discharge machine, to the motor controller **90** and the position recognition device **80**. The position recognition device **80** compares the detected position to the set feed amount.

The controller **2** also includes at least one of a machining time counter **60** and a number of discharges counter **70**. The machining time counter **60** is comprised, for example, of a comparator, an adder, and a clock pulse generator. The number of discharges counter **70** is comprised of, for example, a comparator and a counter. A discharge detector **6** generates a detection signal **S2** if it is detected that current pulse caused by electric discharge has started to flow through the gap. The detection signal **S2** is supplied to the calculating device **10**, the gate signal generator **50**, and the number of discharges counter **70**.

The gate signal generator **50** will now be described in detail with reference to Fig. 2. The gate signal generator **50** includes a selection circuit **51**, an off-time counter **52** for counting off-time, and an on-time counter **53** for counting on-time. The selection circuit **51** is mainly

composed of a storage circuit such as memory. The calculating device **10** supplies selection data

ST to the selection circuit **51** according to a current peak set value. In accordance with the

selection data **ST**, the selection circuit **51** outputs one or more signals from among the gate

signals **G1 - Gn**. Each output terminals of the selection circuit **51** are connected to gates of

switching elements **SW** via AND gates **54**. The calculating device **10** supplies data OF

representing an off-time set value, to the off-time counter **52**. When an output signal **O1** of the

on-time counter **53** is turned off, the off -time counter **52** starts counting. When the count

reaches the off-time set value, the output signal **S1** of the off -time counter **52** is turned on, and

the count is cleared. The calculating device **10** supplies data **ON** representing an on-time set

value, to the on-time counter **53**. When an output signal **S1** of the off-time counter **52** is turned

on, the on-time counter **53** starts counting, and signal **O1** is supplied to the AND gates **54**. When

the count reaches the on-time set value, the output signal **O1** of the on-time counter **53** is turned

off, and the count is cleared. At this time, an inverted signal **O2** of the output signal **O1** is turned

on, and the off-time counter **52** is caused to start counting. The calculating device **10** selectively

supplies data **OC** to the on-time counter **53**, and the on-time counter **53** is provided with a data

selector (not shown). If data **OC** is supplied to the on-time counter **53**, the on-time counter **53**

starts counting when the detection signal **S2** is received.

Removal volume per single discharge **VP** (mm^3) and removal volume rate **Vm**

($mm^{3/}$minute) are stored in the storage device **40** in database format. Removal volume per single

discharge **VP** and removal volume rate **Vm** are correlated to machining conditions. Machining

conditions include the material of the tool electrode **17** and the workpiece **18**, and power pulse

conditions. The value of **Vp** is the volume of material removed from the workpiece **18** with

single discharge. Removal volume rate **Vm** is the volume of material removed per device time. Values **Vp** and **Vm** are obtained by experimentation.

The sinker electric discharge machining method of the present invention will now be described in detail with reference to Fig. 3. The method is executed in the additional machining process using the machining time counter **60**.

In step **S1**, a feed amount **d** equivalent to the dimension **Z** of material to be removed is set using the input device **20**. As shown in Fig. 5, the tool electrode **17** is moved to position **C** spaced apart from the workpiece **18** by the gap size **G**. In step **S2**, the removal surface area **S** (rnm^2) is set using the input device **20**, and the set value is stored in the storage device **40**. Alternatively, the calculating device **10** may set a removal surface area **S** based on three-dimensional shape data for the cavity or the tool electrode **17**, and store the set value in the storage device **40**. The machining conditions for removing material of 1 μm to over ten μm, and in many cases 1 μm to 5 μm, without impairing the small surface roughness of the surface finished in the finishing step, are set. Such machining conditions include on-time of 5 μsecond or less, and peak current of 0.2A - 2A. The set feed amount **d** and machining conditions are described in an NC program, and stored in the storage device **40**. In step **S3**, the calculating device **10** reads our removal surface area **S** and feed amount **d** from the storage device **40**, and calculates removal volume **V** (mm^3). Removal volume **V** is calculated from the following equation.

$V = S \cdot d$

In step S4, the calculating device 10 extracts removal volume rate Vm corresponding to the set machining conditions from the data base in the storage device **40**. In step **S5**, the calculating device **10** also extracts the removal volume **V**, and calculates the machining time **T** (minutes) required to remove material of the removal volume **V** from the following equation.

$T = V/Vm$

The calculating device **10** sets the value **T** at the data terminal of a comparator inside the counter **60**. In step **S6**, the calculating device **10** decodes an NC program, supplies data **ON**, **OF** and **OC** to the gate signal generator **50**, and supplies a command signal to the motor controller **90**. In this manner, the voltage of the power supply **1** is applied via the series circuits **11 - 14** to the gap, and electric discharge machining commences under the set machining conditions. Upon receipt of detection signal **S2** from the discharge detector **6** by the calculating device **10**, the counter **60** counts clock pulses. In step **S7**, when the count reaches the set value **T**, the comparator supplies a completion signal to the calculating device **10**. In response to the completion signal, the calculating device **10** stops operation of the machining time counter **60**, and stops supply of the command signal to the motor controller **90**. The calculating device **10** also deletes selection data **ST** in the selection circuit **51** of the gate signal generator **50**. In this manner, electric discharge machining is completed.

The sinker electric discharge machining method of the present invention will now be described in detail with reference to Fig. 4. The method is executed in the additional machining process using the number of discharges counter **70**.

Description of steps **S1 - S3** has already been given, and so will be omitted. In step **S8**, the calculating device **10** extracts removal volume per single discharge **Vp** corresponding to the set machining conditions from the data base in the storage device **40**. In step **S9**, the calculating device **10** also extracts the removal volume **V**, and calculates the number of discharges **P** required to remove material of the removal volume **V** from the following equation.

$P = V/Vp$

The calculating device **10** sets the value **P** at the data terminal of a comparator inside the counter **70**. In step **S10**, which is the same as step **S6**, the voltage of the power supply **1** is

applied via the series circuits **11 - 14** to the gap, and electric discharge machining commences under the set machining conditions. The counter **70** counts the detection signal **S2**. In step **S11**, when the count of the number of discharges reaches the set value **P**, the comparator supplies a completion signal to the calculating device **10**. In response to the completion signal, the calculating device **10** stops operation of the number of discharges counter **70**, and stops supply of the command signal to the motor controller **90**. The calculating device **10** also deletes selection data ST in the selection circuit **51** of the gate signal generator **50**. In this manner, electric discharge machining is completed.

The embodiments have been selected for the purpose of describing the gist and practical application of the present invention. Various improvements are possible with reference to the above description. The scope of the invention is defines by the scope of the appended claims.